DESIGN, CONSTRUCTION AND CHARACTERIZATION OF A MULTIPLE SENSORS SOLAR RADIATION DETECTOR FOR ISES 2009

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Abstract

The availability of accurate solar data for diffuse, direct and global radiation is a pre-requisite to achieve a suitable exploitation of the solar resources. The objective of the research work is to evaluate the use of a weighted combination of photodiodes measurements with a rotating shadow band for monitoring simultaneously diffuse and beam solar radiation and thus be able to estimate global radiation as well. A set of four diodes with different spectral ranges is proposed as a first prototype. Three different Silicon diodes and one Indium Gallium Arsenide diode are the candidates. A simple signal preamplifier will be used to give signals in the one or few volt ranges that can be measured with any data logger. The diodes will be mounted in a row parallel to the polar axis. Measurements will be taken with and without shadowing with the diodes facing the sun, and in three other shadowed positions to estimate the diffuse component. The shadowing mechanism will be automatically driven and positioned to intercept the direct solar radiation incident on the diodes. A microprocessor system will control the measurements as well as the movement of sensors and shadowband and record the data. The diodes will be calibrated before actual measurements start.

1. INTRODUCTION.

The environmental problems caused by the energy consumption have become strong driving forces in promoting adoption of energy sources, which are environmentally friendly. The majority of Mozambican population uses biomass fuel as a main source of energy. In heavly populated areas, this has caused deforestation. The smoke from open wood fires is often causing lung problems, and is a health hazard. The scarcity of wood will often cause imperfect food preparation, which is also causing severe health problems. Promoting the development of renewable energy sources, such as solar energy systems, therefore, was defined as a national priority in Mozambique, besides the expansion of the conventional electricity grid. The availability of accurate solar radiation comprising the diffuse and direct components as well as the global value is a pre-requisite to achieve an optimal exploitation of the solar resources. Lohmann et al., [2006], states that rising interest in large-scale solar energy applications requires reliable information on solar resources and their variability. Nevertheless, the high capital costs of thermopile based instruments, usually used in pyranometry, represents an important obstacle [Alados-Arboledas et al. 1995] for wide spreading solar radiation installations that could improve the availability of solar radiation data where needed. Solar cell based also, called photovoltaic or semiconductor based pyranometers are widely used as inexpensive instruments to measure solar irradiance [Vignola, 1999]. The main objective of this research work is to develop a low-cost detector with both pyranometer and pyrheliometer capacity combined with control, data logging and storage capacity. To get a robust and cheap system, photo diodes will be used as primary sensors.

A monitoring station typically measures two of the solar irradiance components and calculates the third [Alados-Arboledas et al. 1995]. Often the diffuse component is measured and the direct calculated, because the measure of direct beam requires a relatively expensive equatorial mount, with active tracking of the sun by the pyrheliometer [Batlles, et al.,1995]. Thus, measurements of diffuse component of solar radiation are

commonly made by a pyranometer shielded from the direct component of solar radiation, employing an adjustable shadow ring, shade disc or a shadow band. Figure 1 is an example illustrating a pyranometer shaded with a shadow band for measuring diffuse solar radiation.

Figure 1: A photographic image of a pyranometer with shading band on roof top of the building at the University of Eduardo Mondlane in Mozambique.

However, the shadow ring or shadow band that is used to block the direct component of solar radiation also shades some diffuse irradiance as well [Muneer and Zhang, 2002]. And this, according to Steven and Unsworth [1980] cited by De Oliveira and Machado [2002], causes a systematic underestimation of diffuse solar radiation. Different authors have addressed the necessity of applying a correction factor [Batlles, et al., 1995], to improve the data accuracy measured by a pyranometer with a shadow ring. However, the effect of the shadow ring is difficult to take into consideration because it depends not only on the geometrical characteristic of the device, but also on the hemispherical distribution of solar radiation [Steven, 1984 cited by De Oliveira and Machado, 2002].

Recently rotating shadow band pyranometers (RSP) have come into general use [Vignola, 1996]. RSP's design gives the advantage of using a single pyranometer to measure both, global horizontal and diffuse horizontal, and avoids the constant adjustments of the plane of the ring. They are simpler, less expensive, and more robust [Harrison et al.,1994]. Further, the fact that the three components of solar radiation are derived from a single optical detector, greatly reduces inter-calibration worries over absolute sensitivity and spectral passband. It also makes synchronization of the measurements easier to control [Harrison et al.,1994].

The semiconductor based pyranometers or photodetectors, besides being commercially cheaper compared to the thermopile based pyranometers, are said to be suitable to RSP since they exhibit a short time response. Furthermore, the increased stability of the semiconductor based detectors results in a recommended period of recalibration that is twice as long as required by thermopile instruments (two years versus one year) [Rosenthal and Roberg, 1994]. Other features of the semiconductor based detectors reported by Alados-Arboledas et al. [1995] are the ruggedness and tolerance to soiling. However, these detectors are not without undesirable features [Rosenthal and Roberg, 1994]. Using semiconductor based detectors poses the problems associated with their limited and nonuniform spectral response. A second-order problem with these sensors is their thermal dependence (about 0.15% per C) which could cause relevant change in sensitivity on mid-latitude regions [Michalsky et al., 1987]. An Algorithm to correct for the spectral response of the silicon photodiode detectors was earlier developed by Michalsky [1991] and later King and Myers [1997] also developed a new algorithm. In the present experiment 4 diodes with different spectral characteristics will be used. By a suitable weighting based on comparison with simultaneous measurements by standard instruments, the objective is to find a procedure for obtaining reliable measurements based on diode readings for global, direct and diffuse radiation. Simplifications in the measurement setup, like reduced number of diodes and reduced number of readings, will of course be evaluated along the way.

2. DESCRIPTION OF THE DETECTOR SETUP.

The detectors are two quartets of photodiodes. The diodes in each quartet are mounted in a row below a protecting glass plate. The two quartets are arranged with the top plates at an angle of 60 degrees, and the diode axes in one plane. The assembly is fixed to a motor drive, see Figure 2, to rotate around the polar axis. The quartet plane and the top quartet are parallel to the polar axis, the other quartet faces the no sun hemisphere. The detector rotation is controlled by a microprocessor to take readings in the solar plane as well as in three other positions to get relevant measurements to determine the global radiation. At the solar position, measurements both with and without shadow band will be taken. In the other positions, only readings taken with shadow band are interesting. The four detectors are positioned to allow a narrow shadow band to completely shade the glass cover.

The rotation of two quartets of diodes is an attempt to address the anisotropy problem in the field of diffuse solar radiation extensively reported by several authors such as Battles et al., 1995 cited by De Oliveira and Machado, 2002; Munger and Harbel, 1994. Measurements at several positions make it possible to correct for the general lack of perfect cosine response of photo diodes behind a glass cover. The set of photodiodes has three silicon photodiodes (Si) with different spectral sensitivities and one Indium-gallium-arsenide photodiodes (InGaAs). By choosing suitable combinations of the signals from the Si photodiodes three spectral regions below about 1100 nm may be selected. The InGaAs photodiode is sensitive up to approximately 1700 nm. The sensitivity of the InGaAs peaks at 1500 nm and will probably give a fair mean for the radiation above the Si photodiode region. It is expected that a carefully selected combination of the readings from the photodiode quartets will give a fair representation of the solar radiation spectrum. Only the spectrum range between 1.700 and 3000 nm is not covered by the photodiodes. However, the fraction of solar radiation in this region is small. The photodiodes will be operated in the photovoltaic mode. According to Harrison et al. [1994], this reduces noise and increases the sensitivity and stability. Figure 2 is a schematic representation of the multiple sensor solar radiation detector under development in this research work.

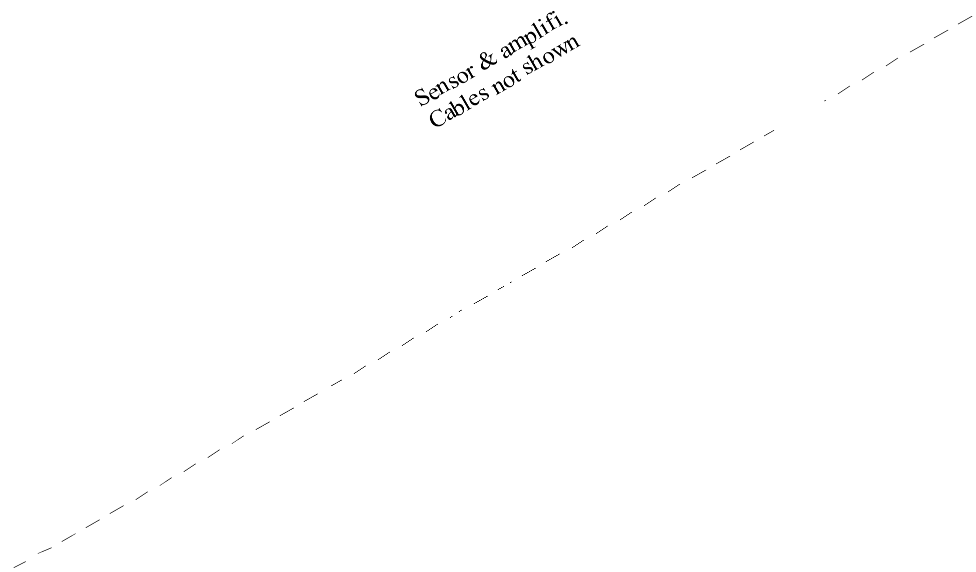

Figure 2: Sketch of the multiple sensor solar radiation detector (TSRSP) under development in this research work. Red colour indicates the sensor assembly which is rotated by a stepper motor. Part of the shadow band assembly is shown on the left hand side.

The implementation of a transimpedance amplifier by using a technique described in Harrison et al. [1994] will be considered in the design.

The shading device is designed to cover a field of view of 5° width to comply with the World Meteorological Organization guide for pyrheliometers. A short rectangular band will possibly be used. It is coupled to a stepper motor, which is microprocessor controlled, to shade the photodiodes to block the beam radiation from hitting photodiodes glass cover.

The solar position will be calculated from the standard equations. Reference positions will be defined for the two stepper motors, one for the detector assembly and one for the shadow band. Correct angular positions are found by movement through the appropriate number of steps. The diode positions are not that critical. The shadow band may be moved slowly across the diode row to exactly determine the minimum. The microprocessor will operate the data reading and control the position of the diode row of detectors as well as the shadow band angle. The design of the data recording is still in development.

Pyranometer design invariably involve compromises on output level, speed of response, ambient temperature dependency, spectral, cosine (i.e. angular) and azimuthal responses and cost to produce [Beaubien et al., 1998]. Attention will be paid to all those aspects.

3. EXPERIMENTAL PROCIDURES

Installation

The challenge experimentally is to mount the photodiodes in a way that will facilitate cleaning and minimize the impact of the weather, such as the reduction of transmission due to deposition of dust as well as salt and other chemicals since the site is located close to the ocean. It will be ensured that the backside of the detector including its electronic components are protected from moisture and dust deposits. Newly calibrated seet of Eppley pyranometer and pyrheliometer will serve as reference instruments. They are already installed on a deck built on the rooftop of the physics building at the University of KwaZulu Natal (Westville Campus) and has been operated since 1997. The roof is ~22.5 m high and ~325 m above sea level. The site was carefully chosen to avoid the effects that could disturb the measurements. No reflecting shiny surfaces such as roofs, light poles, white buildings or buildings with glass are located in the line of sight of the detectors. The MSRD will be mounted such that there is a clear view of the sun at sunrise. A rigid stand with good mechanical stability and well leveled to prevent any movement of the instruments during bad weather days is considered in the design. The stand will be solidly fastened to the roof-deck. The microprocessor control and data logging system will be interfaced to a desktop computer.

Calibration

In the field of instrumentation or metrology, in general, the goal of calibration is to correct for small imperfections that are unavoidable, especially in instruments operating under hostile conditions as instruments for solar radiation measurements will do. A proper calibration of solar radiation instruments is intended to provide accurate measurements which are very important for evaluating the performance of solar systems. Though, it has to be underlined that the calibration of the instrument does not completely eliminate the inaccuracies in the measurements, but improves quality and reliability of measured data.

Prior to the first measurements, calibration of the detectors will be carried out. This calibration focuses on relative scale, that is the relative sensitivity of each sensor composing the quartets of photodiodes and will be established at normal incidence. Subsequently the angular sensitivity will also be investigated. For different situations there are different methods and techniques for calibration of a given instrument. In this particular research work the comparison technique will be used. Other techniques will be investigated.

Characterization

Characterization of the detector will be focused on the spectral and cosine (angular) responses, also the influence of environmental conditions on detector readings will be investigated. The main objective on the characterization of the detector is to ensure good quality of collected data.

Finally, an overall analysis of the measurements made with the detector will be done in order to establish the level of reliability of the data collected. This will also help to validate the results of the research. Some uncertainty and inaccuracy is a part of every radiometer measurement [Rosenthal et al., 1994]. Therefore, before examining the data, it is important to understand the measurement uncertainties associated with the use of each radiometer. These uncertainties give an indication of the magnitude of the measurement inaccuracies possible even when the radiometer involved is correctly calibrated and properly operated [Rosenthal et al., 1994].

4. Expected results

Since the detector is under development no result can be presented presently however, the basic idea is that the magnitude of direct solar radiation as measured by the pyrheliometer can be considered as a combination of the diode measurements, analytically written as

$$E_D = \sum_{k=1}^{4} b_k I_{Dk}$$

Where E_D, represents the magnitude of the direct solar radiation, b_k, is a coefficient to be determined, I_{Dk}, are the photodiodes readings corresponding to the direct solar radiation magnitude. The coefficient b_k are found by minimizing, that is

$$Z = \sum_{i=1}^{N} \left[E_D{}^i - \sum_{k=1}^{4} b_k I_{Dk}{}^i \right]^2$$

Where N corresponds to total of data sample, i indicates that we are using data for measurement number i and Z/N, indicates the mean variance for each measurement, and is an estimate for the goodness of fit. If necessary, the above summation may be done for sub-regions of the external variables to establish dependence on e.g. temperature, solar height or clearness index.

The diffuse radiation will be estimated in a similar way. In this case there will be statistical fluctuations due to the differences in operation of the detector systems. But mean values even over short periods should be comparable.

The final test of the instrument will be to see if the readings of the calibration instruments can be matched, once all coefficients are established. Such a test is also suitable to identify variables that are systematically causing a difference. In turn addressing indentified problems should in the end give a good instrument.

5. CONCLUSION

The merit of the system discussed above has to be proven by measurements and careful analysis of the data. The intention is to provide a simple and cheap instrument, simplifications with respect to the above description will be considered in the process. But we think that the use of simple, cheap and stable detectors with high response, robust electronics and microprocessor control will finally yield an interesting instrument.

6. REFERENCES

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